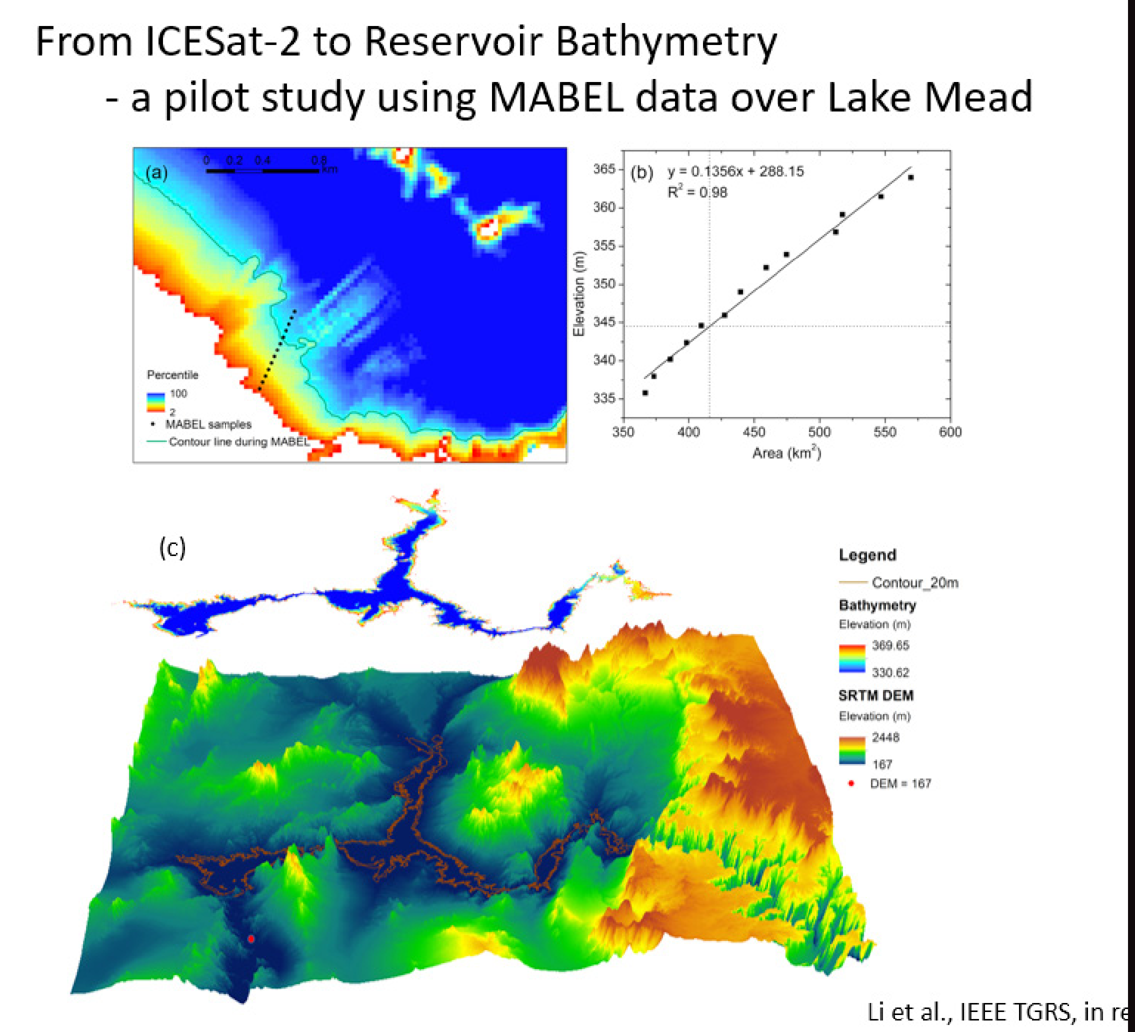
ICESat-2
ICE, CLOUD, AND LAND ELEVATION SATELLITE-2

National Aeronautics and Space Administration

Developing an ICESat-2 Based Lake Bathymetry Product for Improved Reservoir Management: A Pilot Study over Lake Mead. Early Adopter PI: Huilin Gao, Zachry Department of Civil Engineering, Texas A&M University; Science Definition Team Partner: Michael F. Jasinski, Goddard Space Flight Center, NASA. Precise lake bathymetry (i.e., elevation/contour) mapping is essential for optimal decision making in water resources management. Traditional survey methods are usually cost-expensive and are unable to provide reliable information over regions that are difficult to access. In this Early Adopter application, we have developed an algorithm and tested it at Lake Mead by combining elevation values from the prototype ICESat-2 lidar instrument, the Multiple Altimeter Beam Experimental LiDAR (MABEL), with data from a long-term water occurrence map (generated from Landsat images). This helps us to explore the potential of generating high-resolution reservoir/lake bathymetry at a global scale using ICESat-2 data, which will enhance water resources management from many aspects.



Lake bathymetry. We developed a novel algorithm to generate lake bathymetry results using the prototype for the ICESat-2 photon counting instrument—MABEL. The MABEL elevations were paired with data from a Landsat based water occurrence percentile image to establish an Elevation-Area relationship, which in turn was re-applied to the percentile image to obtain a map of the lake's bathymetry. The bathymetry image was then embedded onto the Digital Elevation Model. This algorithm was validated over Lake Mead using bathymetry survey data. We demonstrated that the resultant bathymetry shows high accuracy compared to local lidar survey data.

Globally available. Locally practical. Reservoir bathymetry information plays a critical role in optimal decision making associated with water resources management. Since reservoir water availability is inferred from the water level, precise bathymetry directly leads to accurate storage estimations. Similarly, it can improve the quantification of evaporation loss, which is the product of area and evaporation rate. Although bathymetry is an important parameter for both hydraulic and water management models, it has virtually always been oversimplified within these models. Within individual reservoirs, sedimentation is highly related to—and affected by—bathymetry. By leveraging ICESat-2 observations, a locally applicable and globally available bathymetry dataset is promising.

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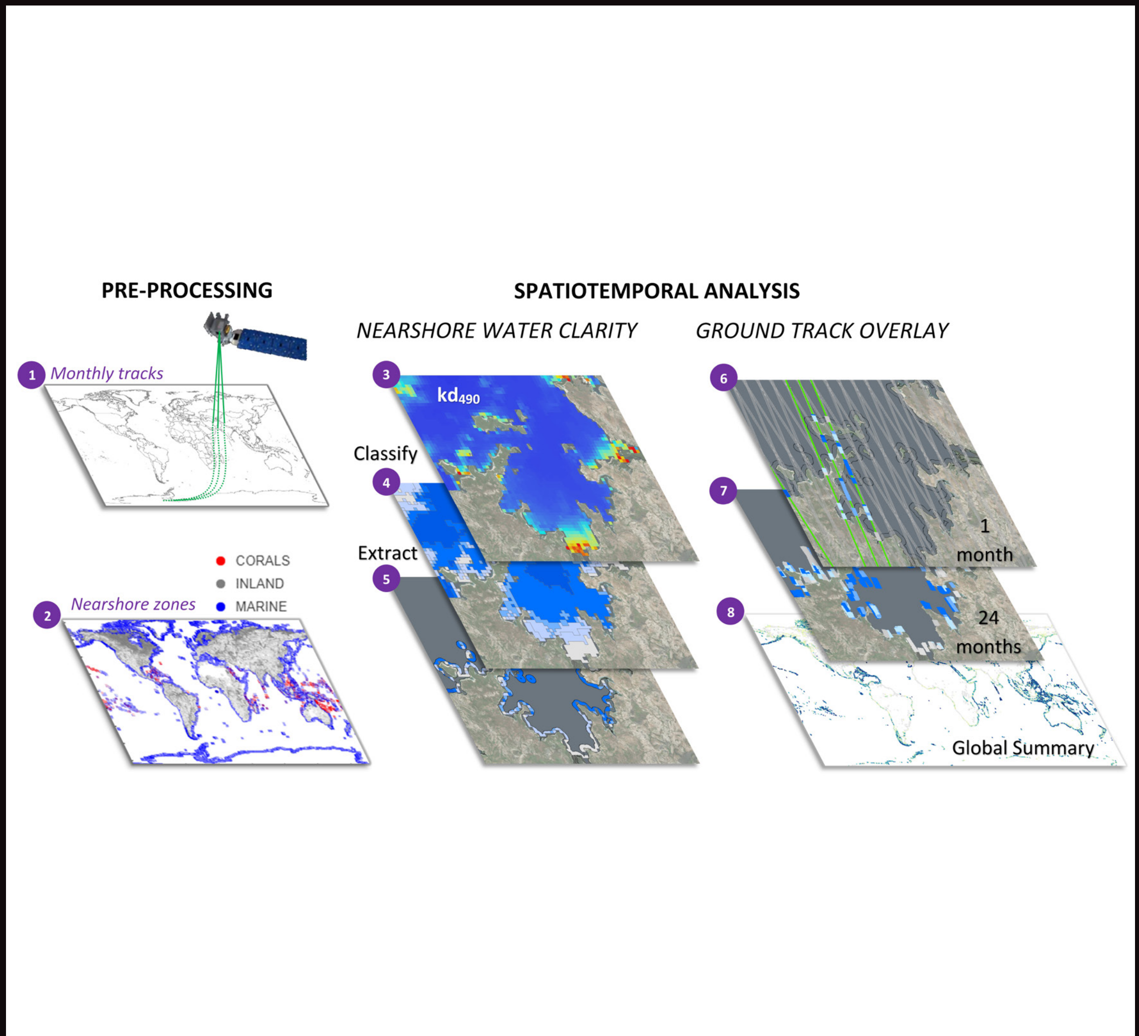
ICESat-2 Coastal Mapping and Monitoring. Early Adopter PIs: Christopher E. Parrish & Nicholas Forfinski-Sarkozi, Oregon State University; Science Definition Team Partner: Michael F. Jasinski, Goddard Space Flight Center, NASA. This project seeks to apply ICESat-2 ATLAS data and derived geospatial products to coastal science and engineering applications. The OSU project team is currently working with NASA and with members of the Joint Airborne Lidar Bathymetry Technical Center of Expertise (JALBTCX) research community to investigate the potential to map bathymetry using an active-passive sensor fusion approach that integrates ICESat-2 ATLAS and Landsat 8 Operational Land Imager (OLI) data. Seafloor photon returns from ICESat-2 ATLAS, even if sparse, may be used to constrain relative bathymetry derived from multispectral satellite imagery, such as from Landsat 8 OLI, to map nearshore bathymetry over large spatial extents. This entirely satellite-based approach to nearshore bathymetric mapping could be valuable in addressing the current global nearshore data void, especially in remote coastal regions.



Spatiotemporal water clarity analysis. The team is currently using ICESat-2 predicted orbit tracks in combination with worldwide coastal water clarity, derived from Visible Infrared Imaging Radiometer Suite (VIIRS) data, to identify areas where the spaceborne bathymetric mapping procedures developed in this project may be viable. This analysis will be used to select project sites for investigation during ATLAS's first year on orbit and to compile reference data to test the approach.

Coastal hazards. With approximately 40% of the world's population living within 100 km of the coast, data are urgently needed to support policy decisions addressing coastal erosion, inundation due to hurricanes, tsunamis, and other coastal hazards. Nearshore data are also required for mapping and monitoring coral reef ecosystems around the world.

Reference: *Forfinski-Sarkozi, N. and Parrish, C. 2016. Analysis of MABEL Bathymetry in Keweenaw Bay and Implications for ICESat-2 ATLAS. Remote Sensing 8(9):772.*

APPLICATIONS

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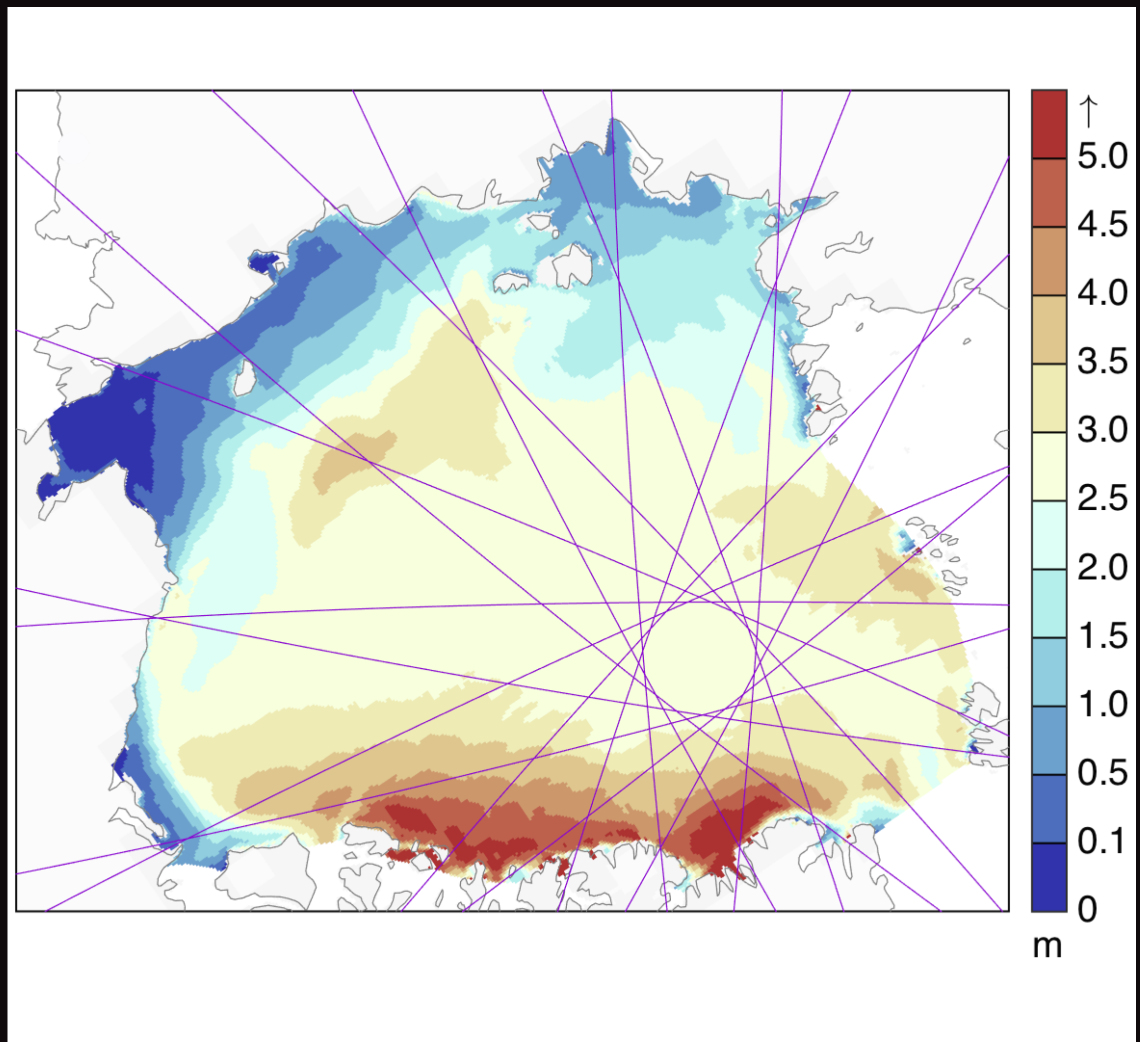
ICESat-2 emulator for the CICE Consortium sea ice model. Early Adopter PIs: Andrew Roberts - Los Alamos National Laboratory, Adrian Turner - Los Alamos National Laboratory, Alex Jahn - University of Colorado; Science Definition Team Partner(s): Ron Kwok, NASA Jet Propulsion Lab. Our team is developing an ICESat-2 emulator for the Los Alamos Sea Ice Model (CICE) Consortium sea ice model to facilitate detailed evaluations of computer simulations used to make future projections of the state of Earth's sea ice cover. The CICE sea ice model is used in more than 20 countries to research sea ice processes and their interactions with the climate system, in 12 coupled models or Earth System Models (ESMs) used for the Intergovernmental Panel on Climate Change Fifth Assessment Report, and by the U.S. Navy for sea-state forecasting. It is difficult to place error bounds on ice thickness derived from measured sea ice freeboard due to heterogeneous snow cover and ice porosity. By contrast, calculating model freeboard from ice thickness is much easier and makes it desirable to evaluate ESMs with the ICESat-2 freeboard emulator.



Apples-to-apples Comparison. The ICESat-2 emulator for CICE samples sea ice and snow thickness at the same place and time as freeboard samples from the ICESat-2, and calculates satellite-equivalent freeboard, thus enabling an apples-to-apples comparison with predictive Earth System Models. This figure demonstrates the concept for the Regional Arctic System Model (RASM) that uses CICE. It shows central Arctic 91-day July to September mean sea ice thickness field in RASM sampled at 20-minute model time-steps (color), with overlaid ICESat-2 reference ground tracks spanning ~1 day, from which model freeboard is sampled during in CICE run-time.

Coordinated disaster response. Our work seeks to help improve short-term predictions as well as decadal climate projections of the Arctic biophysical state, in line with the National Strategy for the Arctic Region. Through the integration of our work into the mentioned models, we will help improve national defense environmental forecasting capabilities, coordinated disaster response, including oil spill mitigation, and ongoing support of field, energy exploitation and international policy development. Project outcomes will help with Department of Defense strategic planning with regard to minimizing the risk of having inadequate capabilities and insufficient capacity to operate in the Arctic when required, as a result of changing climate and geostrategic situation.

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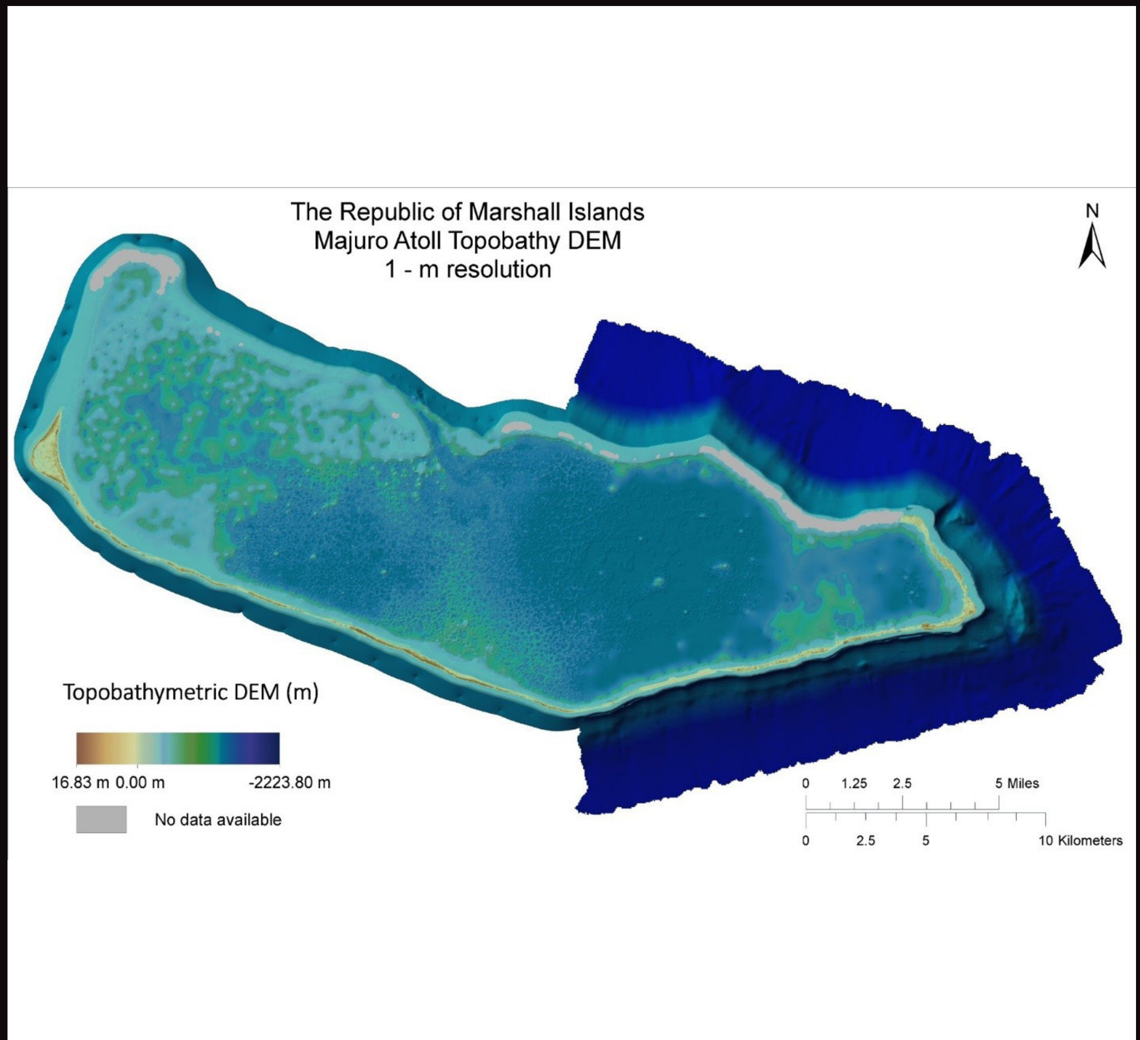
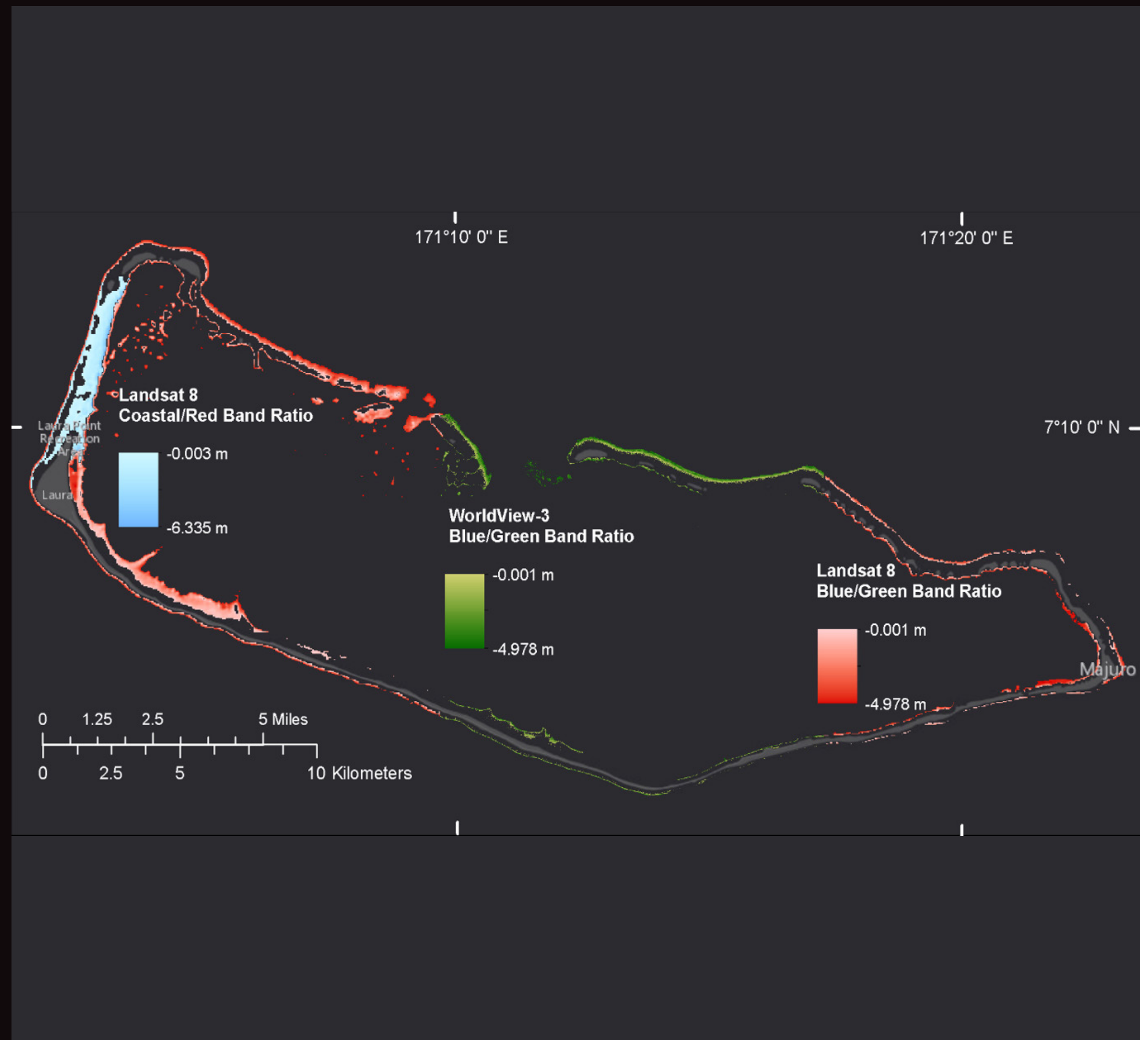
Satellite-Derived Bathymetry (SDB) Mapping Task Team. Jeff Danielson, U.S. Geological Survey (USGS) Earth Resources Observation & Science Center. The U.S. Geological Survey (USGS) Coastal National Elevation Database (CoNED) Applications Project develops enhanced topographic (land elevation) and bathymetric (water depth) datasets that serve as valuable resources for coastal hazards research and flood inundation modeling. Through the Interagency Working Group on Ocean and Coastal Mapping (IWG-OCM), a SDB Mapping Task Team has been set up to cooperatively investigate remote sensing methods and techniques for generation of reliable satellite-derived bathymetry mapping products. At the forefront will be the use of ICESat-2 data for providing water depth calibration along with validation of land vegetation heights for biomass estimation and terrain modeling.



Majuro Atoll Topobathymetric Elevation Model. With an estimated maximum elevation of only 3-meters above sea level, the Majuro Atoll, capital of the Republic of the Marshall Islands (RMI), is extremely vulnerable to sea-level rise, tsunamis, storm surge, and coastal flooding that could impact the sustainability of the infrastructure, groundwater, and ecosystems. Located in the northern tropical Pacific Ocean, the waters surrounding the Majuro Atoll land areas are relatively shallow with poorly mapped bathymetry. To support the modeling of storm- and tide-induced flooding, the USGS CoNED Project in collaboration with the U. S. Department of Interior (DOI) Pacific Islands Climate Adaptation Science Center (PI-CASC) and the USGS Coastal-Marine Hazards and Resources Program developed an integrated 1-meter topobathymetric digital elevation model (TBDEM) for the Majuro Atoll, RMI, using a combination of nine best available topographic and bathymetric data sources. Image Credit: USGS.



Satellite Derived Bathymetry. Defining near-shore water depth (bathymetry) is problematic because ships cannot operate close to the shore while collecting bathymetric soundings. Because highly dynamic coastal shorelines can be affected by erosion, wetland loss, hurricane impacts, sea-level rise, urban development and population growth, consistent bathymetric data are important and needed to better understand sensitive coastal land/water interfaces. Ocean optics using passive multispectral imagery, such as Landsat 8 and DigitalGlobe WorldView-3 have been used to estimate near-shore bathymetry for the Majuro Atoll. The satellite reflectance data were correlated with the water depth, using bathymetric (green) lidar data from the Naval Oceanographic Office (NAVOCEANO). Image Credit: USGS.

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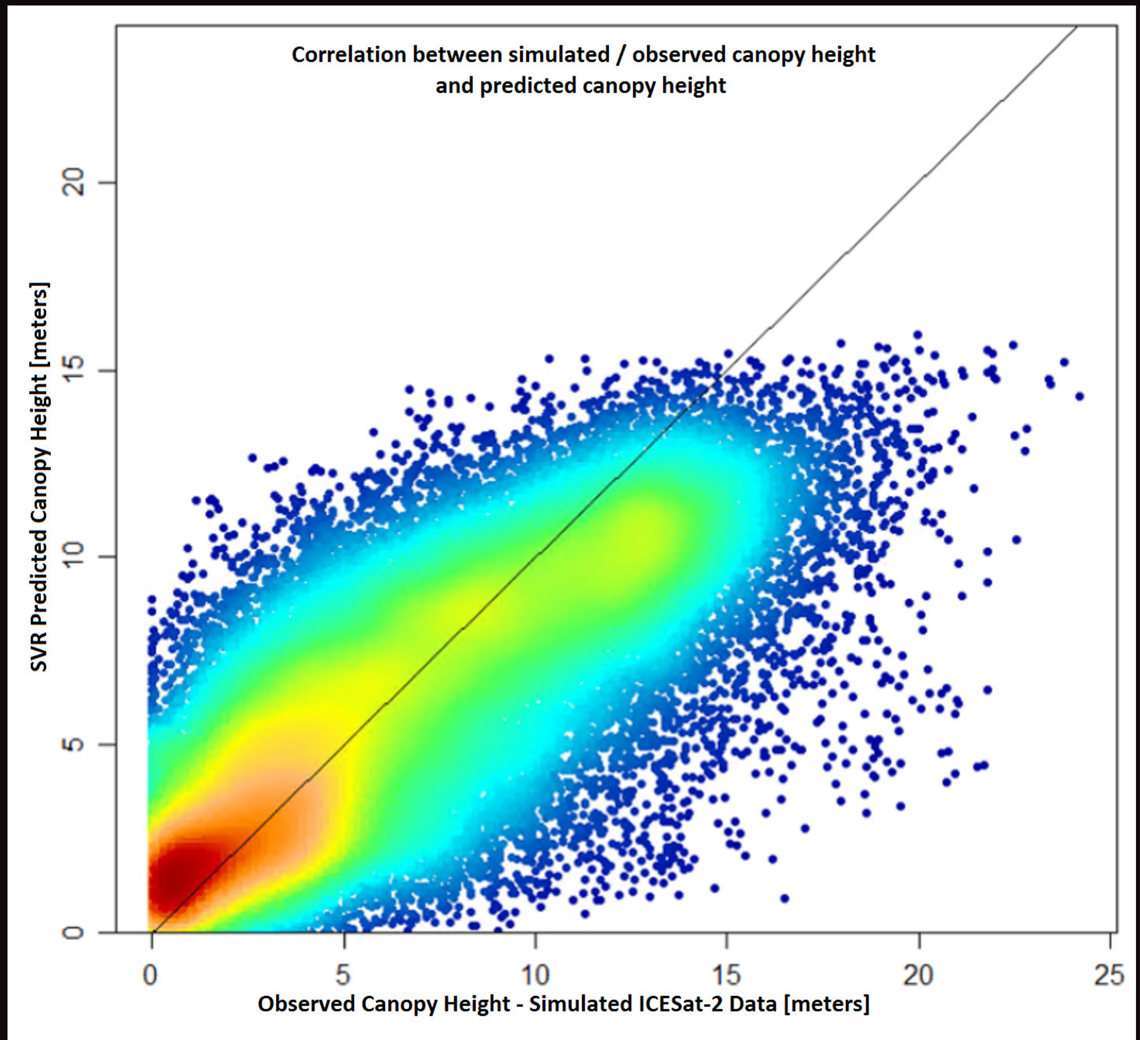
A Danish innovation funded project on optimizing wind energy estimates using satellite data. Early Adopter PIs: Merete Badger, Kenneth Grogan, Philip Graae, & Mikkel Rasmussen, DHI-GRAS A/S (Denmark); Science Definition Team Partner(s): Amy Neuenschwander, University of Texas. The InnoWind project is a joint research group working towards improving the use of geospatial data in the wind sector, by leveraging state of the art remote sensing methodologies in an effort to improve wind energy resource modelling and assessment. Canopy height data provided by ICESat-2 is intended to be used for calibration and validation Support Vector Regression, with a multitemporal stack of Sentinel-1, Sentinel-2, and Landsat 8 data as the predictors. By creating a high resolution gridded canopy height dataset, the estimate of the 'roughness length (Z0)' can be significantly improved, which in turn helps reduce the uncertainty in wind flow models.



Forest canopy height. By using the coarser ICESat-2 ATL08 Science Data Product as calibration and validation to create a 10m resolution canopy height model, the accuracy of local wind modelling can be significantly improved. The illustration shows the correlation between a simulated ICESat-2 'Observed Height' dataset and the SVR predicted canopy height. In order to account for varying ecosystems, regional correlations will be established which will allow for the methodology to be used for mapping forest canopy height across the globe in an effort to support the efficient establishment of renewable energy in emerging markets.

Wind conditions. Through the predicted forest canopy height, the 'roughness length' can be estimated, which in turn is used as one of the driving layers in a Computational Fluid Dynamics model, with the goal of accurately modelling the wind conditions in the study area. With an accurate wind model, the renewable energy companies, such as Vestas and Vattenfall, will be able to make sound long term decision on where to erect new wind turbines and how multiple wind turbines in a given area will interact. This helps ensure a profitable venture and reliable energy production for years to come and is but one step towards a more sustainable future.

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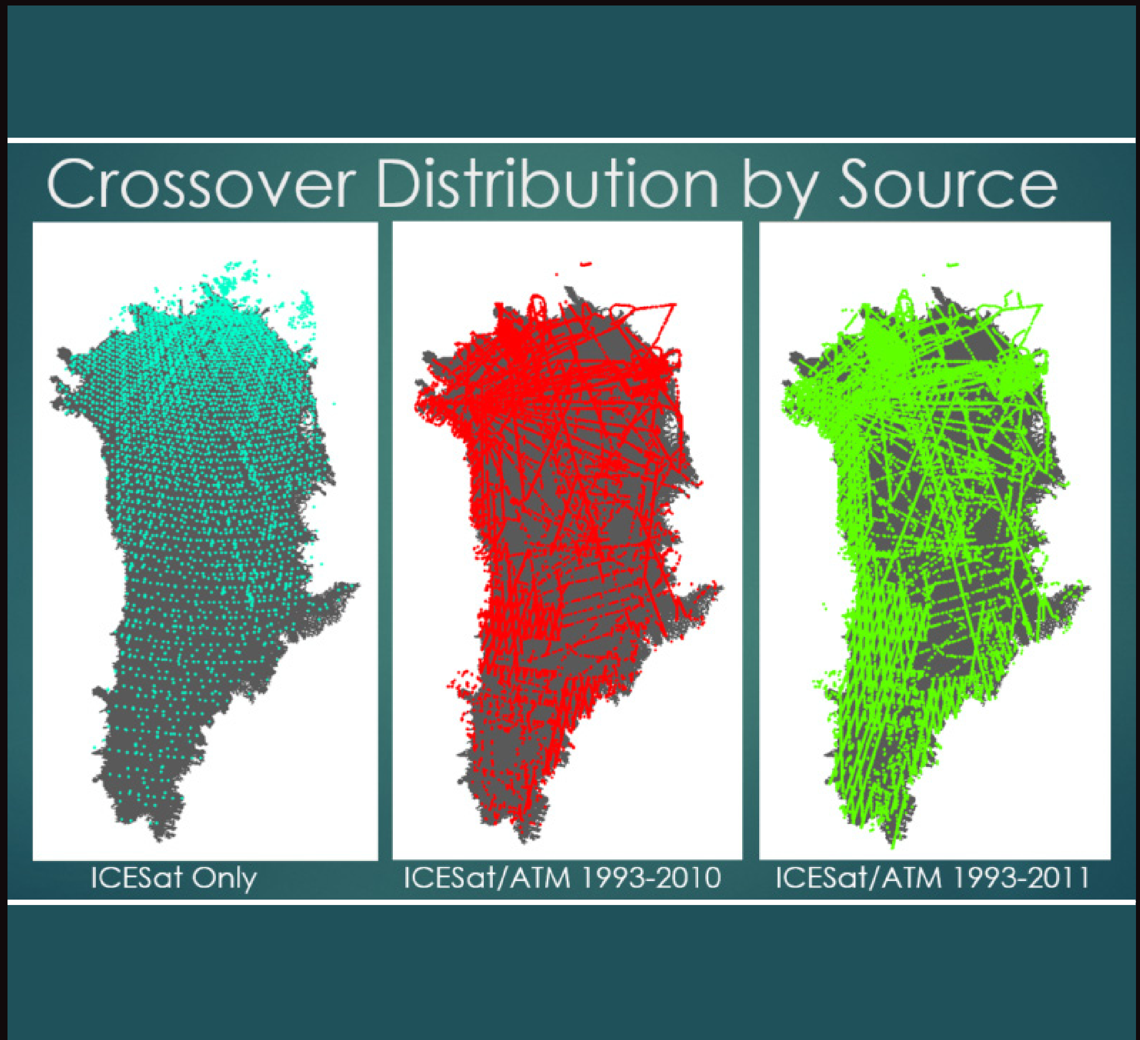
Applications of ICESat-2 in volcanic and geohazards-related research. Early Adopter PI: Greg Babonis, State University of New York at Buffalo; Science Definition Team Partner(s): Alex Gardner, NASA Jet Propulsion Lab. Hazard management often involves the use of computational flow models that simulate granular mass flows over real topography, in the form of Digital elevation models (DEMs). DEMs of volcanoes have typically been generated from terrestrial or private airborne altimetry flights over specific volcanic complexes, from optical imagery and platforms such as the Advanced Spaceborne Thermal Emission and Reflection or Satellite Pour l'Observation de la Terre when available, or from NASA IceBridge and ICESat-1 datasets where available. However, there exists a need for systematic updating of DEMs available at volcanoes. Additionally, deformation of volcanic flanks is a useful indicator in eruption forecasting, and is often monitored using ground-based sensors (tiltmeters, GPS) or, less frequently, InSAR. High temporal resolution, satellite-based deformation monitoring of flank deformation could provide the basis for improved deformation monitoring and eruption forecasting at poorly instrumented volcanoes.



Enhanced DEMs. ICESat-2 data will be used as control points to generate high spatial and temporal resolution DEMs to be used as model inputs for the prediction of evolving PDC hazards and to further the understanding of physical volcanic processes. Additionally, repeat track and crossover analysis, combined with DEMs, will be used to monitor volcanic lava dome volume changes and flank deformation. We use waveform analysis of current LiDAR data to derive roughness characteristics of volcanic deposits, in order to map different components of PDCs, i.e., dense block-and-ash flows and dilute pyroclastic surges. We anticipate developing techniques to use ICESat-2 data in a similar fashion.

Volcanic hazard mitigation and management. DEMs are rarely accurate for long at active volcanoes, as strong depositional and erosional processes rapidly change the landscape. Topographic changes during an ongoing eruptive crisis can have important hazard implications, as in-filled valleys are less able to contain subsequent pyroclastic density currents (PDCs: hot avalanches of volcanic rock and gas) and steeper average drainage slopes can increase PDC mobility. As such, frequently updated DEMs are important to hazard mitigation and management. ICESat-2 data may improve the elevation data around volcanoes that have not been monitored previously, reducing errors and uncertainty in the hazard models used to estimate the possible movement of volcanic mass flows across the landscape.

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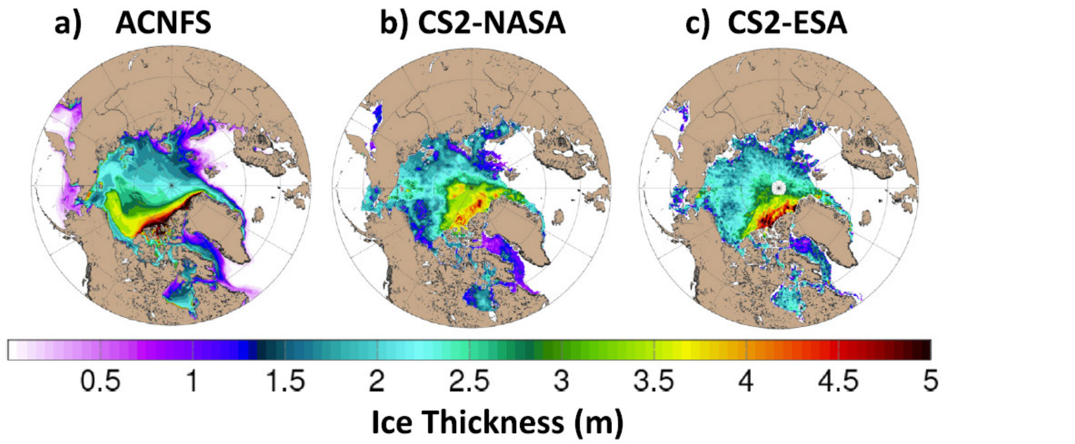
Use of ICESat-2 data as a Validation Source for the U.S. Navy's Ice Forecasting, **Early Adopter PI (s): Richard Allard and David A. Hebert**, Naval Research Laboratory; **Science Definition Team Partner: Sinead Farrell**, University of Maryland. The U.S. Navy has been producing forecasts of the ice conditions in the Northern Hemisphere since the early 1980's. Currently, the Navy has two operational systems predicting the changing ice environment: 1) the Global Ocean Forecast System (GOFS 3.1 – https://www7320.nrlssc.navy.mil/GLBhycomcice1-12), which produces forecasts for both the northern and southern hemisphere, and 2) the Arctic Cap Nowcast/Forecast System (ACNFS – http://www7320.nrlssc.navy.mil/hycomARC), which is a subset of the global system and produces forecasts for only the northern hemisphere. ICESat-2 data products will provide a unique opportunity to evaluate the ACNFS/GOFS performance and subsequently enhance model skills through ICESat-2 data assimilation.



Monthly averaged March 2014 sea ice thickness (m) for (a) operational ACNFS (b) CS2-NASA, and (c) CS2-CPOM.

Using a hindcast approach. Both ACNFS and GOFS ingest near real time observations within a 72-hour timeframe. The U.S. NRL will investigate how to improve the assimilation of the 45-day latency ICESat-2 ice thickness-derived product by running a twin hindcast of the operational system (ACNFS or GOFS 3.1) lagged by 45 days. Hindcasts are a way of testing a model against known or closely estimated inputs for past events to see how well the model matches the known results. Periodically, either seasonally or once per year, ice thickness observations will be assimilated into the ACNFS/GOFS 3.1 systems to create a more realistic forecast product. Until ICESat-2 data is available, ice thickness data available from other sources (e.g. CryoSat-2, SMOS) will be used to reinitialize ACNFS and compare results with data from ice mas balance buoys and upward looking sonar ice draft data. Allard, R.A., et al. Utilizing CryoSat-2 sea ice thickness to initialize a coupled ice-ocean modeling system. Adv. Space Res. (2018), https://doi.org/10.1016/j.asr.2017.12.030

Arctic operations. Dramatic changes of the Arctic climate system demand high resolution and accurate sea ice forecasts by ACNFS/GOEFS in the marginal ice zone for a number of operational applications, including Arctic shipping. The ICESat-2 geolocated photon and sea ice elevation data products will provide a very high-resolution precise geolocation of sea ice, open water and leads. This capability will enable the Navy to expand the marginal ice zone ice edge validation to the entire global domain. An improved ACNFS/GOFS 3.1 will benefit the U.S. Navy, as well as external customers that include the National/Naval Ice Center; the National Weather Service in Anchorage, Alaska; and the National Oceanic and Atmospheric Administration (NOAA).

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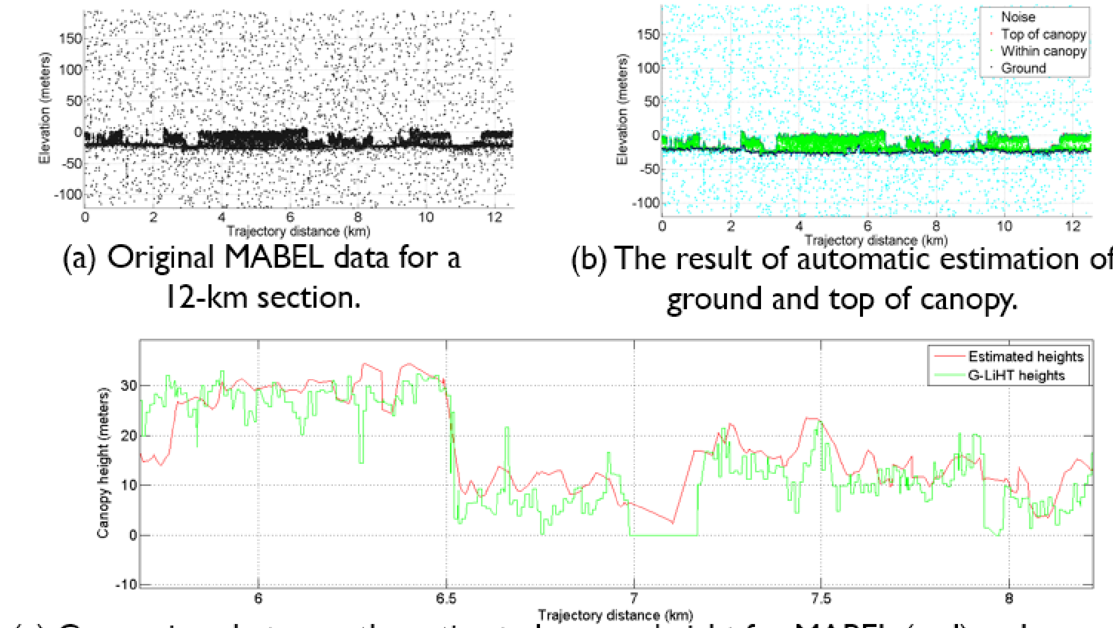
Detection of ground and top of canopy using simulated ICESat-2 lidar data. Early Adopter PI (s): Randy Wynne and Lynn Abbott, Virginia Polytechnic Institute and State University; Science Definition Team Partner: Sorin Popescu, Texas A&M University. Our Virginia Tech team is currently developing algorithms and software to identify ground, top-of-canopy (TOC), and canopy height using simulated ICESat-2 data. Repeated largescale estimates of forest biomass are critically important for understanding the global carbon cycle and its dynamics. The importance of finding efficient ways of quantifying terrestrial carbon stocks at a global scale has increased due to concerns related to global climate change. In order to track changes at the global scale, recurring high altitude observations are needed, and satellite-based LiDAR systems, such as will be available with ICESat-2, can provide these observations.



(a) Original MABEL data for a 12-km section.

(b) The result of automatic estimation of ground and top of canopy.

(c) Comparison between the estimated canopy height for MABEL (red) and ground-truth values obtained from G-LiHT (green).

Profile view of a section of North Carolina, near Wilmington

Noise reduction. Much of the prior research into the estimation of forest biomass using LiDAR is not directly applicable to ICESat-2, because of the change in technology from the GLAS waveform system to the ATLAS photon counting system. Photon detectors introduce new challenges to the prediction of biomass, particularly substantial levels of ambient noise that appears in the photon cloud above and within the vegetation canopy and below the ground. The anticipated noise levels will make the detection of the top of the canopy and the ground itself very challenging, particularly in complex forest ecosystems. Our team is developing a novel two-phase algorithm for estimating ground and top-of-canopy surfaces from photon-counting LiDAR point clouds. We have demonstrated improved accuracy of point cloud classification for ground surface estimation and are exploring how to improve separation between bare ground and vegetated areas.

Forest characterization. Estimates of forest canopy heights are important to track forest growth over time, as well as forest-related harvesting and land use. For this Early Adopter project, we are working with the American Forest Management and USDA Forest Service as potential end users. Our Early Adopter activities will help their land management work, including reforestation and inventory services, by improving the measurement accuracies that can be obtained to better characterize forests. M. Awadallah, A. L. Abbott, and S. Ghannam, "Segmentation of Sparse Noisy Point Clouds using Active Contour Models," to appear in Proceedings: *IEEE International Conference on Image Processing (ICIP 2014)*, Paris, France, Oct. 2014

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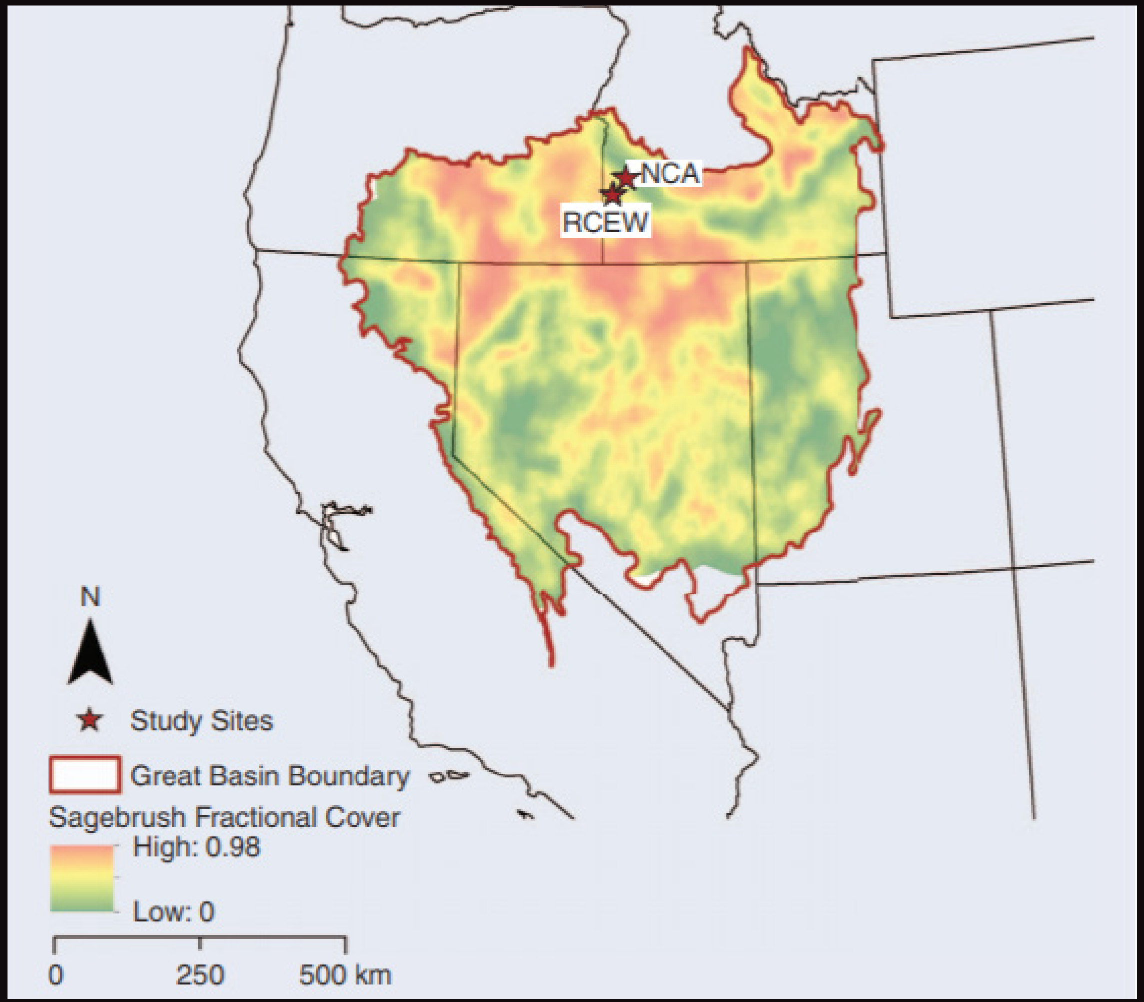
Use of ICESat-2 data for improved terrestrial carbon estimates with semiarid ecosystem structure. Early Adopter PI: Nancy Glenn, Boise State University, Boise Center Aerospace Laboratory; Science Definition Team Partner(s): Amy Neuenschwander, University of Texas. There are significant needs for reliable estimates of the health and biomass of drylands, where 35% of the world's population resides. Drylands are particularly vulnerable to simultaneous changes in climate, fire, invasive species, and anthropogenic stressors, and they can be difficult to monitor with remote sensing, given their sparse, heterogeneous structure. Changes in dryland vegetation structure, such as in the semiarid Great Basin in the western United States, have resulted from invasion of exotic annuals such as cheatgrass (Bromus tectorum), resulting in an increase in fire frequency and spread at regional scales. This Early Adopter project tests prototype ICESat-2 data (MABEL) with airborne and terrestrial laser-scanning and optical remote sensing data that have previously been used to derive biomass, cover, and height information in the Great Basin.



Canopy characteristics of semiarid vegetation. While previous work on vegetation analysis with ICESat-2 has focused on forests with a full canopy, this project seeks to determine the sensitivity of ATLAS data to derive key canopy characteristics that would allow mapping of semiarid ecosystem structure at landscape scales, such as the sagebrush steppe in the Great Basin. Our analyses has demonstrated that simulated ATLAS data have the sensitivity to quantify height metrics of semiarid vegetation with minimum heights of 1 m and 30% canopy cover. These results are compelling, especially with the potential to combine future ICESat-2 data with optical data such as Landsat 8 to improve both height and cover estimates. The synergistic use of Landsat 8 and ICESat-2 data may enable wall-to-wall estimates of vegetation community structure and carbon for semiarid ecosystems.

Great Basin land management. Targeted fuel reduction and prevention of conversion to fire-prone grasslands in the Great Basin is a high priority for land management agencies such as the Bureau of Land Management (BLM). Our Early Adopter project focuses on integrating ICESat-2 data into management driven projects in the Great Basin with the BLM and within the Joint Fire Sciences Program. These projects work to ensure the maximum integration of science into management decisions through partnerships and technology transfer. The projects are also part of the Great Basin Morley Nelson Snake River Birds of Prey National Conservation Area (NCA) Science Working Group, and associated partners enabling a wide management-ased audience.

N. F. Glenn, A. Neuenschwander, A. A. Vierling, L. P. Spaete, A. Li, D. Shinneman, et al., "Landsat 8 and ICESat-2: Performance and potential synergies for quantifying dryland ecosystem vegetation cover and biomass," Remote Sens. Environ., vol. 185, Mar. 2016

APPLICATIONS

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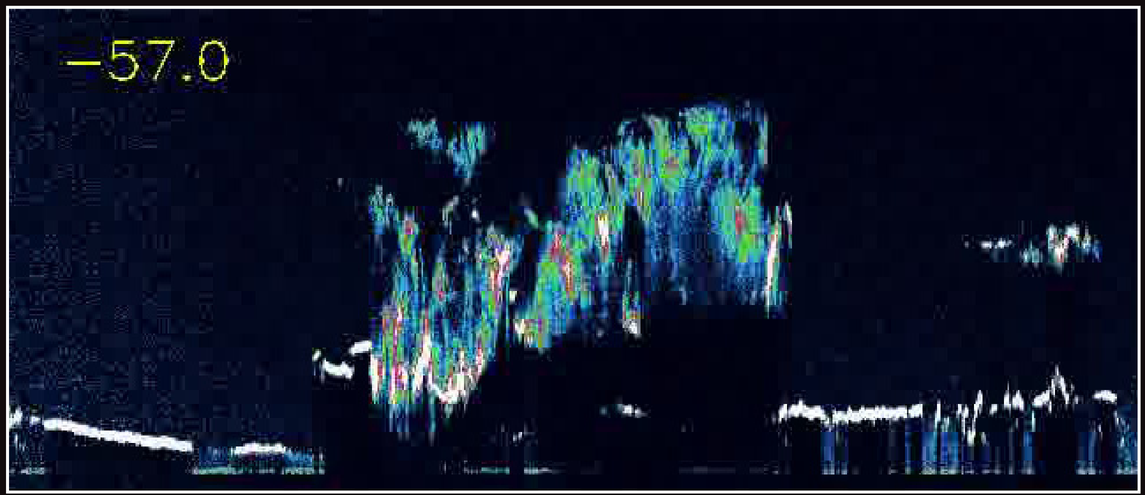
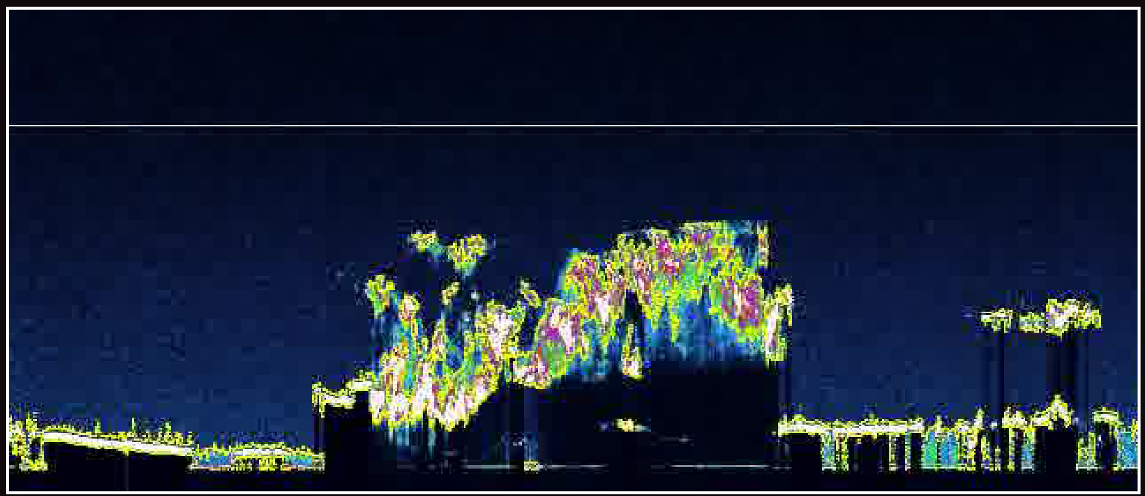
Detection and Mapping of Blowing Snow from ICESat-2 Data: Applications to Ice-Sheet Mass Balance and Transportation.

. Early Adopter PI (s): Ute Herzfeld, University of Colorado Boulder; Science Definition Team Partner: Stephen Palm, Science Systems and Applications, Inc., NASA Goddard. Our ICESat-2 Applications Early Adopter Project is to examine the ICESat-2 atmospheric data products with respect to their information on blowing snow. While the first products that come to mind in atmospheric layer detection are clouds and aerosols, blowing snow is a phenomenon and a highly variable atmospheric layer that has many applications in society and in science. Blowing snow has detrimental effects on society, as it reduces visibility and hinders transportation. It also plays a key role in important science questions including ice sheet mass balance, heat budget in the ice-atmosphere system, water budget of high-latitude regions and reconstruction of paleoclimatic records from ice cores.





Blowing snow. To detect highly atmospheric layers, which are highly variable in time and space, we have developed the Density-Dimension Algorithm. A version of this algorithm will be applied to identify blowing snow. The goal of this EA project is to investigate the suitability of the ICESat-2 blowing-snow product for two very different, but equally important applications: (1) Suitability for hazard warning in modern transportation, and (2) Role of blowing snow in assessment of melt events in Greenland and Antarctic ice sheets, which is typically conducted using energy balance modeling - the blowing snow is expected to offset the results.

Transportation hazard warning. Blowing snow is common in Antarctica during winter; however, blowing snow is also present across the United States during winter and can lead to significant hazards for air and ground transportation. High winds create thick layers of blowing snow, which hinders the heavy traffic of a heavily populated region, such as the Denver-Boulder-Colorado Springs-Fort Collins Metropolis. For this research, we will select two roads—I25 (N-S) along CO Front Range (densely populated) and I70 (E-W) across the Rockies—to analyze time dependence of atmospheric data and real conditions. Our Early Adopter project will examine the feasibility of an ICESat-2-derived blowing snow product and its use by transportation authorities to inform hazard warning. ICESat-2 will have ground tracks with separation of several kilometers (10-20 depending on latitude). In addition, cloud cover may also obscure our ability to detect blowing snow layers on some days, while on clear days blowing snow will be obvious.

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